Search for $0\nu\beta\beta$ with CUORE

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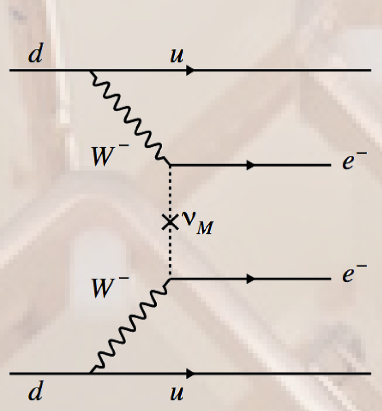
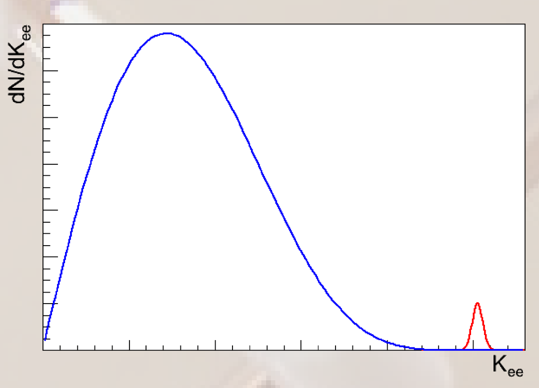
Neutrinoless double beta decay

The Majorana/Dirac nature of the neutrino is one of the still open questions in our understanding of the fundamental building blocks of matter. Probing this would give us hints into other fundamental questions like whether the lepton number is an absolute symmetry and the origin of matter-antimatter asymmetry. Neutrinoless double beta decay ($0\nu\beta\beta$) experiments are the most feasible method for answering this question and in the past decade many experiments have begun to search for this process.





Unlike a typical two neutrino double beta decay ($2\nu\beta\beta$) which is allowed in the Standard Model and has been observed, $0\nu\beta\beta$ deposits all of the energy of the decay into three detectable decay products.

$$(Z, A) \rightarrow (Z + 2, A) + 2e^- + 2\bar{\nu} \quad (2\nu\beta\beta)$$
$$(Z, A) \rightarrow (Z + 2, A) + 2e^- \quad (0\nu\beta\beta)$$

We seek to detect this process by searching for a tell-tale bump at the end of the $2\nu\beta\beta$ spectrum. A positive detection of this decay would indicate lepton number violation and also provide a measurement of the effective Majorana mass($m_{\beta\beta}$) of the neutrino,

$$1/T^{0\nu} \propto G^{0\nu}(Q, Z)M^{0\nu}|\langle m_{\beta\beta}\rangle|^2$$

Bolometric Method for $0\nu\beta\beta$ Detection

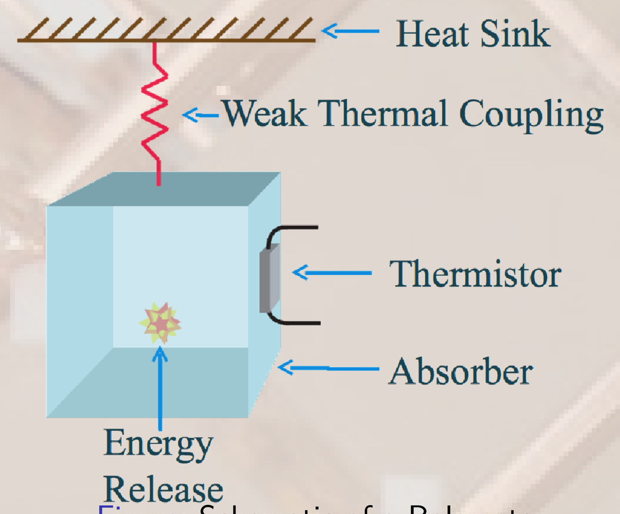


Figure: Schematic of a Bolometer

A decay event in our detector causes a change in temperature. The change in temperature is directly proportional to the energy of the event.

$$\Delta T_{Event} = \frac{E_{Event}}{C_{Crystal}}$$

However, to resolve individual nuclear decays, we have to make our detector very cold – 10mK!

$$C^{-1} \approx 100\mu K/MeV$$

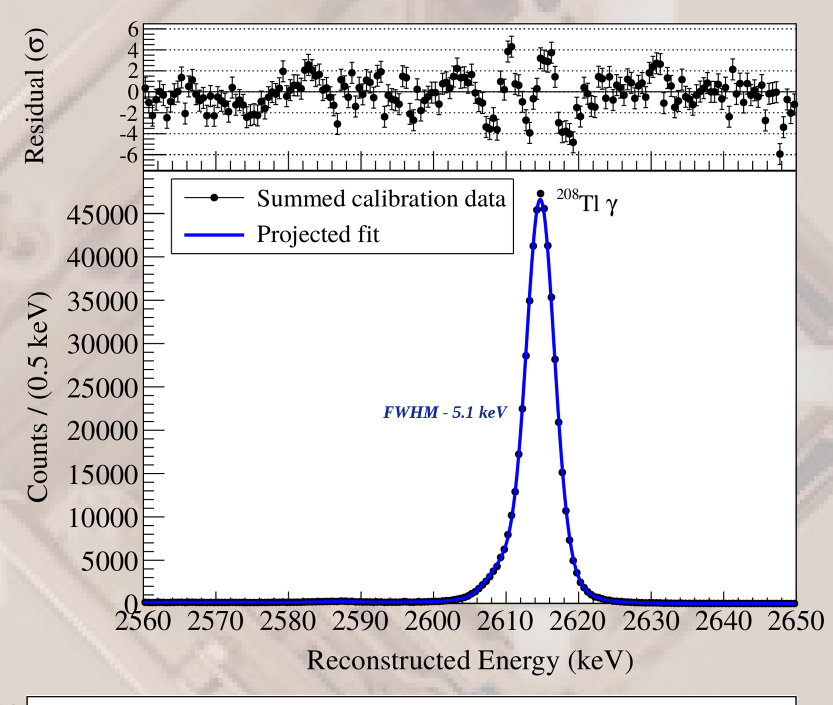
The tiny changes in temperature are read out using thermometers with an exponential dependance on temperature.

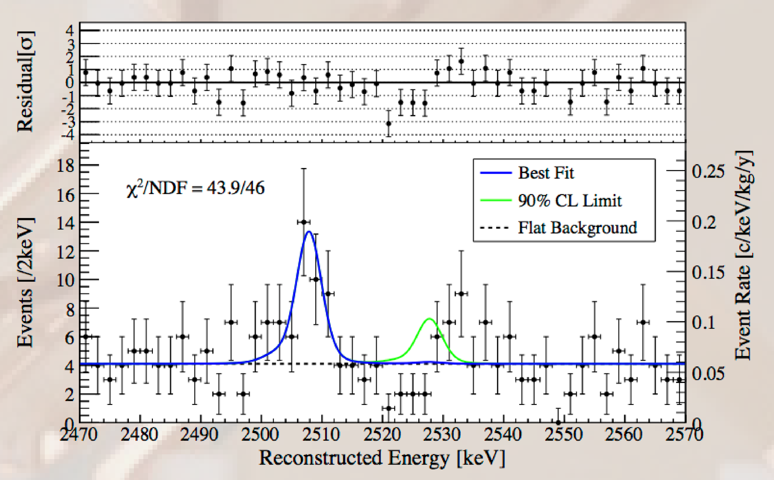
$$R = R_0 e^{\sqrt{T_0/T}}$$

Which yields a measurable change in resistance ($\sim$3MΩ/MeV).

CUORE-0 Results

- It has provided a direct measurement of the improvement in background level from Cuoricino, its predecessor, to CUORE. As well as a test of the CUORE style tower wiring.
- CUORE-0 accumulated 9.8kg(^{130}Te)·yr of exposure running for two years from March 2013 to March 2015.
- Combined with Cuoricino, CUORE-0 set the most stringent limit on $0\nu\beta\beta$ decay of ^{130}Te at 4.0×10^{24} (yr) (90% C.L.).





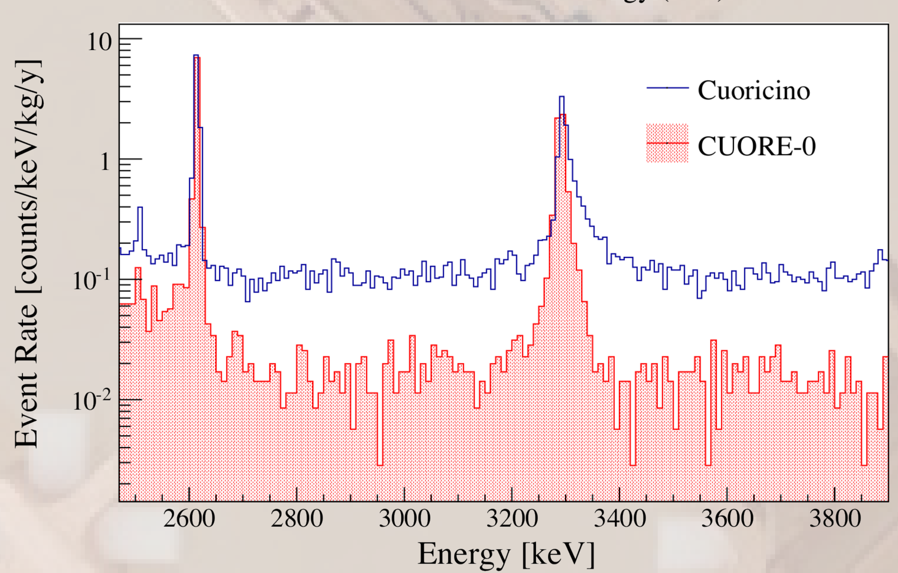
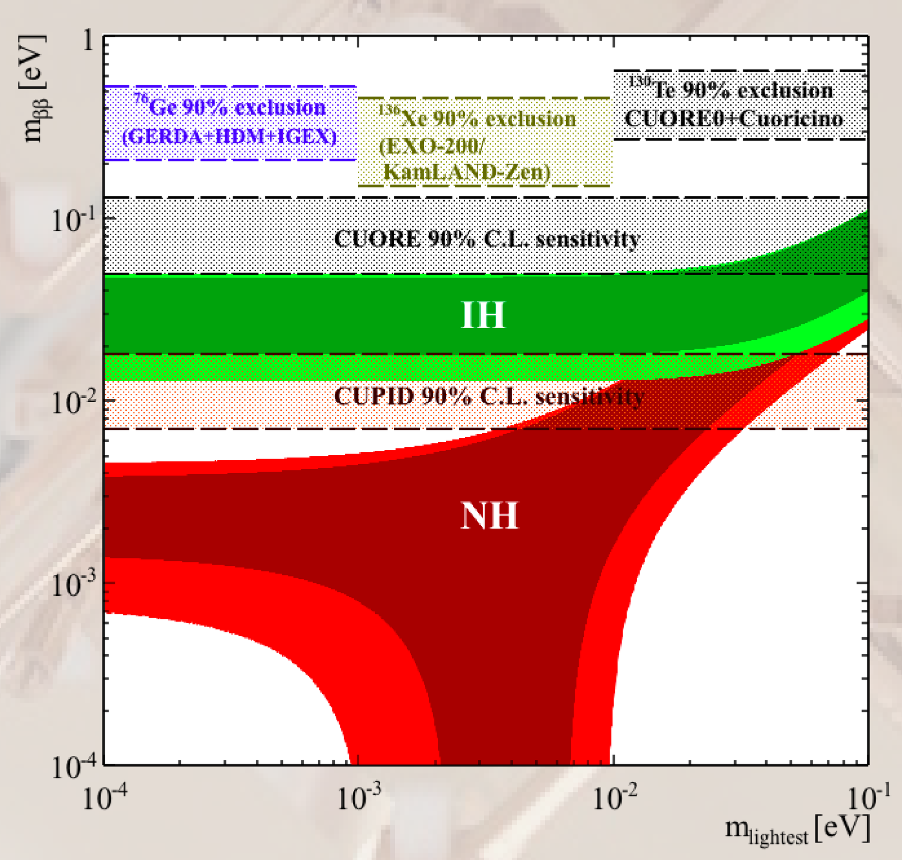


Figure: RESULTS FROM CUORE-0

- Degraded α-continuum rate measured to be 0.020 ± 0.001 cnts/keV/kg/yr.
  - ⇒ Factor of 5-6 improvement over Cuoricino.
- A resolution of 5.1 keV (FWHM).
- Background in the region of interest (ROI) now dominated by γ's from the old Cuoricino cryostat.

Projected Sensitivity

- The CUORE sensitivity was computed by mean of a Bayesian analysis with a toy-MC approach.
- A median exclusion sensitivity of $\sim 9.5 \cdot 10^{25}$ yr is expected with after 5 years of data collection.
- A 99% discovery sensitivity equal to the CUORE-0 and Cuoricino limit can be achieved after 1 month of operation.
- CUORE is expected to begin data taking by the end of this year and surpass the current best available limits of $m_{\beta\beta}$ on TeO_2 half life within few weeks of its operation, eventually being sensitive to a $\sim 10^{26}$yr half life.



- The goal of CUPID is to cover the whole inverted hierarchy, thereby either confirming or rejecting the existence of majorana neutrinos with $\Delta m^2_{23} < 0$.
- CUPID is a next generation bolometric experiment beyond CUORE, currently in active development.

CUORE & Future

The Cryogenic Underground Observatory for Rare Events (CUORE) at Gran Sasso National Laboratories is one of several new $0\nu\beta\beta$ experiments; in particular CUORE will search for $0\nu\beta\beta$ in ^{130}Te.

The CUORE Detector

- The CUORE detector will consist of 988 (5 cm)^3 crystals of $^{nat}TeO_2$.
- A total mass of $\sim$741 kg, 206 kg of which is ^{130}Te.
- Each 750g crystal acts as both source and detector.
- Temperature is read out using a Neutron Transmutation Doped Germanium thermistor (NTD).
- Energy resolution of $\sim$5keV at 2.5MeV.

CUPID

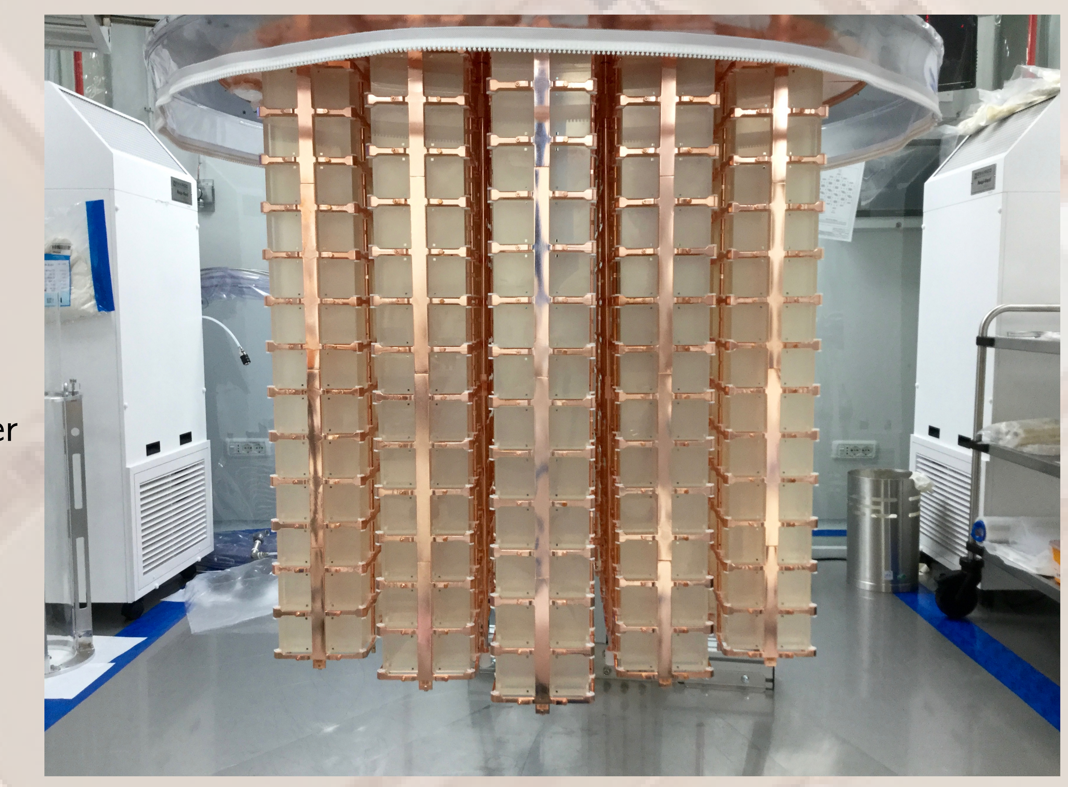
- CUPID (**CUORE U**pgrade with **P**article **ID**entification is the next generation of CUORE currently in R&D phase.
- Goal of CUPID is to reduce background to negligible levels by tagging events using Cherenkov or scintillation light to differentiate β/γ vs α events.

CUORE Past vs future

	Cuoricino	CUORE-0	CUORE	CUPID
Background (cnts/keV/kg/yr)	0.153	0.06	$\lesssim$.01	$\lesssim 10^{-4}$
FWHM at 2615 keV (keV)	5.8	4.9	$\lesssim$ 5	$\lesssim$ 5
Lifetime Limit (yr) (90% C.L.)	2.8×10^{24}	2.7×10^{24}	9.5×10^{25}	$10^{27} - 10^{28}$

Detector Assembly

- The detector assembly began with gluing the NTD thermisters and heaters to the TeO_2 crystals using a specialized mechanical robot arm.
- Then the crystals were assembled into towers and wired.
- It was followed by wirebonding the NTDs to the wire pads on the copper frames. This is done using a customized, vertically mounted wire bonding machine.
- In total, tower assembly included about 10000 parts and 8000 wirebonds and was completed successfully last summer.



⇒ All the steps of assembly was done under constant N_2 flux to reduce exposure to contaminants.

Finally, this fall, all these towers were assembled in to the final detector configuration in the CUORE cryostat.

CUORE Cryostat

- Total mass to be cooled down inside the cryostat 15 tonnes (Detectors + Shielding + Support structures)
- Commissioning completed in March 2016 with the successful cooldown of the cryostat with the Pb shielding and support structures (sans the detector).
- We obtained a stable and reproducible base temperature of 6.3 mK over a period of more than 2 months.
- We got encouraging detector performance on 8 detector array (Mini-tower). We measured an energy resolution close to 10 keV. The resolution was limited by the vibrational and electrical noise which we are planning to improve on during the final run.
- Detector installation completed in a specially constructed clean room, constantly flushed with Radon free air
- We are closing up the cryostat and preparing for the cooldown now Detector operations by the end of the year

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